ENGINEERING PROPERTIES OF CHICAGO SUBSOIL

BY

ARTHUR CHENG CHUNG CHANG

B.S., St. John's University, Shanghai, China, 1940
M.S., University of Illinois, 1941

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
[redacted] ENGINEERING IN THE GRADUATE SCHOOL
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INTRODUCTION

Because of the presence of a thick layer of soft, compressible clay, most of the heavy buildings in early days in Chicago settled excessively. As engineers and architects became aware of the importance of this soft clay deposit, records were made of the subsoil conditions and of observations concerning the behavior of the structures. These records, extending over a period of about 60 years, constitute the source of information for this investigation.

The first purpose of this investigation is to assemble all available data concerning the subsoil of Chicago for the use of engineers and architects in their practice; a general description of the subsoil conditions within the city limits is given. The second purpose is to summarize the quantitative test data pertaining to the soil in order to permit a study of the Chicago experience in terms of modern soil mechanics; a summary of the test data concerning Chicago clays from many different sources is presented.

Of the boring logs collected for the preparation of this investigation, one series is especially reliable and suited to the Chicago clay. The boring logs of this series are based not only on the foreman's description of samples, but also on a field penetration test. As a result, the terminology is quite consistent. The borings of this series were made over a period of many years, and were scattered over many parts of the city. They constitute the basic material for the preparation of this investigation. They are designated as the Smith Series because most of the borings were made by R. C. Smith, civil engineer, Chicago, Illinois. The boring logs together with those collected from other sources are filed and stored in Room 113, Talbot Laboratory, University of Illinois, Urbana, Illinois.

Another important series of borings was made in 1939 and 1940 during the construction of the initial system of Chicago subways. The borings were spaced at about 300-foot intervals along the subway routes and continuous clay cores were taken in 2-inch diameter thin-wall seamless steel tubing from the top of the clay deposit to a depth about ten feet below the bottom of the subway tubes, approximately 35 feet below the Chicago city datum. Information given in the boring logs includes a verbal description and the results of penetration tests, compression tests, and water content determination for all borings, and Atterberg limit data for 15 borings.

On the basis of the boring study, the Chicago subsoil appears to consist of a series of layers, from the ground surface down, as follows:

Fill (Topsoil if there is no fill)
Sandy silt
Tough yellow and blue clay crust
Very soft blue clay
Soft blue clay
Stiff blue clay
Tough blue clay
Very tough blue clay
Hard blue clay
Very hard blue clay
Dense silt and boulders
Bedrock

This sequence does not hold for every locality in Chicago, but it does represent the typical section where the softest clays are present. Since this terminology was first suggested by R. C. Smith, it is called the Smith Soil Classification in this investigation.

As the test results considered in the second part of this investigation are expressed in terms of modern soil mechanics, correlations with the Smith soil classification are made to the natural water content and unconfined compressive strength of the clay. These correlations are made by comparing the soil strata described in the Smith boring logs with the corresponding parts of

the neighboring subway borings. The results of the correlations are:

Smith Classification	Natural Water Content % of dry weight		Compressive Strength Tons per square foot	
	Average	Range	Average	Range
Very soft clay	30.1	39-26	.31	.24- .39
Soft clay	24.8	28-22	.50	.39- .63
Stiff clay	22.4	24-20	.80	.63- 1.00
Tough clay	20.0	22-18	1.30	1.00- 1.60
Very tough clay..	18.3	21-16	2.00	1.60- 4.00
Hard clay	13.7	18-11	5.30	4.00- 6.60
Very hard clay....	10.7	13- 8	8.40	6.60-16.80

These correlations are well established for the very soft, soft, and stiff clays. Some modification of the physical constants for the stiffer clays may be necessary when more data are availble.

SUMMARY OF CHICAGO SUBSOIL CONDITIONS

In the Chicago area, the present ground surface is quite level and does not reflect the irregularity of the bedrock surface because of the successive deposition of glacial and lacustrine deposits. The ground surface lies between Elevation +10 and +30 except at Blue Island ridge near the intersection of Western Avenue and 95th Street, and in the area west of Narragansett Avenue and north of North Avenue, where the ground surface rises to +90 and +80 respectively. The present ground surface in the downtown district is from 5 to 10 feet above the virgin soil and has been built up by miscellaneous fills.

Below this fill a layer of sand, silt, or a combination of the two, with a thickness varying from zero to over 20 feet, exists in the east portion of the city. This mantle has the appearance of fine sandy material, changing to grey silt for the lower 2 or 3 feet, and is non-uniform in denseness. Footings of comparatively light buildings usually are set on this layer.

Between the sand mantle and the underlying bedrock, there is a clay deposit of glacial origin. Its thickness varies from zero where the bedrock outcrops, to more than 100 feet where the bedrock descends to 130 feet below the Chicago city datum. Its stiffness varies from very soft, soft, stiff, tough, very tough, to hard and very hard as the depth increases. The surface of the

clay deposit has been desiccated and oxidized to a tough yellow clay crust streaked with blue, which generally merges into the underlying blue clay within a depth of 3 to 6 feet. On this crust, the footings of most of the early heavy buildings were located directly or indirectly.

The very soft, soft, and stiff clays are plastic, sticky, impervious, ready to flow under pressure if not confined, and contain a considerable amount of rock fragments. The thickness of these clays varies from zero where the tough clay is at the surface to a maximum of 60 feet near the intersection of the branches of the Chicago River. In the entire downtown area, the thickness is between 30 to 60 feet. It decreases with increasing distance from this area. The area west of Pulaski Road is free of the soft clay layer. This clay contains a high water content and is called the "compressible clay" in this investigation, because it is responsible for most of the settlement of buildings which have their footings set on the overlying tough clay crust.

Beneath the compressible clay is a layer of tough and very tough clay. The boundary between the overlying compressible clay and this tough clay layer is distinct. Numerous sand, sand and gravel, and silt pockets exist in this layer and also in the overlying compressible clay. The thickness of the tough clays varies from zero to 40 feet or even more. Most of the buildings founded on pile foundations have their piles supported at some depth within this tough clay layer.

According to records made during the construction of the City's subway system, the shape of the sand or silt pockets in the soft and tough clay layers may be very irregular; the thickness may be from several inches to more than 10 feet and the length may be from several feet to a block long. Often they are dry, but if water is introduced into them, they will act as quicksand.

The hard and very hard clays lying under the tough and very tough clay layer have a thickness varying from zero where the rock outcrops to more than 30 feet. The change from the overlying tough clay layer to this hard clay layer is sudden and distinct. The hard and very hard clay layer contains stones, boulders, and rock fragments of sizes larger than those imbedded in the soft and tough clay. Caissons are often founded on this layer.

Very often a deposit of unstratified sand, silt, gravel, boulders, and laminated clay or of their combinations, several inches to more than 20 feet in thickness, is located between the hard clay and the bedrock. This deposit is usually quite pervious. When water is present, the material appears to be rather soft and causes troubles when caissons are dug into it, but the same material is compact in its undisturbed natural bed.

The bedrock at Chicago is an excellent limestone of the Niagaran formation, varying between 215 and 450 feet in thickness. Foundations on this bedrock are considered safe for any load that it is practicable to place on the rock. The surface of the bedrock is extremely uneven; in some places it outcrops and in some places drops to 130 feet below the lake level. As a whole the surface is not horizontal but slopes gently downward from the southwestern part of the city toward the northeast with numerous uphills and depressions.

Maps showing the contours of each clay layer and of the bedrock surface, the thickness of the compressible clay, and the extent of the tough clay crust and of the overlying sand mantle within the city are presented in the thesis; they are omitted in this abstract.

SUMMARY OF PHYSICAL PROPERTIES OF CHICAGO SUBSOIL

Properties of soil may be placed in three main categories: (1) Classification data, of use in identifying parts of a soil deposit by means of certain definite physical properties. The natural water content, Atterberg limits, and plasticity index are included in this group. (2) Engineering properties, of direct use in civil engineering prolems which deal with stability and compressibility. The unconfined compressive strength, sensitivity ratio, compression index, coefficient of consolidation, and unit weight are discussed under this group. (3) Special properties, not of direct engineering use, but of interest to research workers in soil mechanics. The grainsize distribution, modulus of elasticity, direct shear and triaxial compression test data are included in this group.

Summary of the Study of the Classification Data:

1. The natural water content of Chicago clay decreases with

the increase of the stiffness of the clay. Values of the unit weight, unconfined compressive strength, compression index, and coefficient of consolidation can be obtained from the natural water content by means of correlations developed in the thesis.

2. Statistically, the value of the liquid limit of the softer clays is larger than that of the harder clays. Furthermore, the liquid limit increases with the increase of the natural water content, according to the approximate relation

$$L_w = 0.67w + 16.5$$

where L_w is the liquid limit and w the natural water content, both expressed as percentages of the dry weight of the soil.

3. The plasticity index varies directly with the liquid limit; for Chicago clays, the following equation can be used to show the approximate relationship between the plasticity index and the liquid limit:

$$I_w = 0.7043\ L_w - 7.85$$

Here I_w is the plasticity index and L_w is the liquid limit, both in percent of dry weight of soil.

Summary of the Study of the Engineering Properties:

4. A geometric series exists among the average values and also among the ranges of the unconfined compressive strength of the strata as classified by the Smith soil classification. The unconfined compressive strength of the Chicago clay increases with the decrease of natural water content and liquid limit.

5. The unconfined compressive strength of the samples obtained in 2-inch diameter thin-wall steel tubes varies directly with that of hand-carved undisturbed samples of the same material, and has an average value about 75% of that of the undisturbed samples. The average ratio between the remolded and undisturbed compressive strengths is 33%. The ratio is smaller for low-strength and larger for high-strength samples.

6. The unit weight of saturated Chicago clay can be computed by means of the expression

$$\gamma = \frac{171.3\,(1 + w)}{1 + 2.745w}$$

Here γ is the unit weight in pounds per cubic foot and w is the natural water content of the clay, expressed as the ratio between weight of water and dry weight of soil.

7. The compression index of the Chicago clay can be computed by means of the expression:

$$C_c = 1.613w^2 + 0.556w - 0.0129$$

if the natural water content w of the clay (expressed as a ratio) is known. Consequently the settlement ΔH of the clay due to an increment of load Δp can be computed by:

$$\Delta H = (0.591w - 0.0129)\,H \log\frac{p_o + \Delta p}{p_o}$$

Here H is the thickness of the clay layer and p_o is the present over-burden pressure.

8. An average value for the coeffcient of consolidation for Chicago clays is 0.0123 square inches per minute. The error is not likely to exceed $\pm 50\%$.

Summary of the Study of the Special Properties:

9. The grain-size distribution of the tough yellow clay crust indicates that this material has the same uniformity and fineness as the underlying soft clay. This suggests that the tough clay crust was derived by the desiccation of the underlying soft clay.

10. The modulus of elasticity of the undisturbed samples increases with the increase of the unconfined compressive strength of the samples.

11. For all practical purposes, the value of the angle of the internal friction ϕ for plastic Chicago clay in the field is equal to zero and the average shearing resistance in the field is equal to one-half of the average compressive strength of 2-inch diameter thin-wall steel-tube samples.

This study of the properties of Chicago subsoils suggests that in order to design foundations soundly, the unconfined compressive strength and natural water content of the soil at the site should be known. Consequently, tests should be made on

fairly undisturbed samples to determine these two properties, to supplement the information given in the accompanying maps, whenever an important structure or an unexplored location is involved. In such cases, the cost of the tests will be well compensated by the information secured from them.

VITA

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